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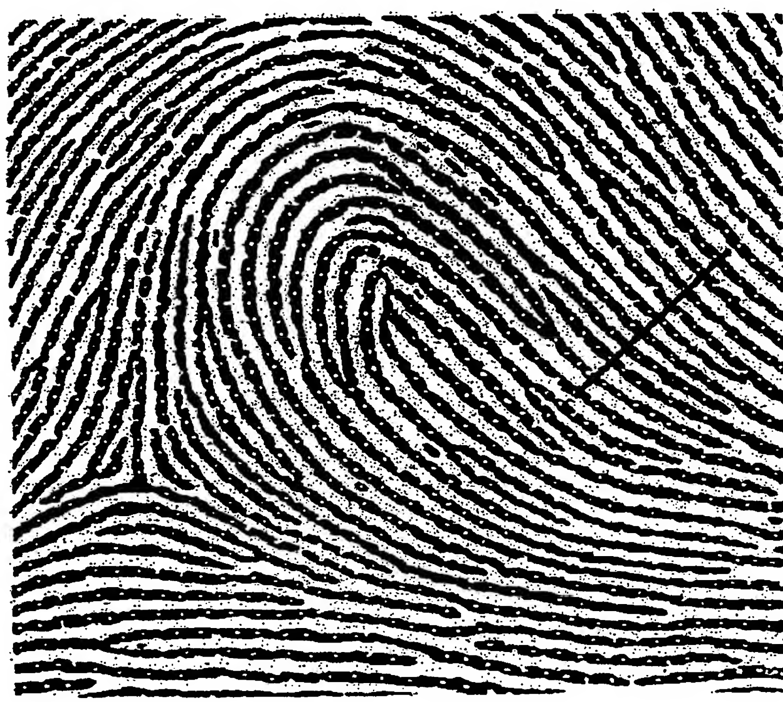
(54) Title: FINGERPRINT ANALYSIS METHOD

(57) Abstract

A method for determining the probable gender of an individual based on his or her fingerprints is provided. The method relies upon a strong correlation between fingertip ridge width and gender, which is independent of body size. The method is useful in the fields of forensics, forensic pathology, and forensic anthropology.



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FINGERPRINT ANALYSIS METHOD

FIELD OF THE INVENTION

The invention has applications in the fields of fingerprint measurement and analysis, forensics, and forensic anthropology.

BACKGROUND

Friction ridge skin is very different from the skin covering the rest of the body. On humans, this special skin is located on the fingertips, palms, soles and toes. In humans, dermatoglyphics (specific characters of ridged skin), begin to form around the 3^{rd}- 4^{th} month of fetal life and are usually fully developed around the 6^{th} month in utero. The actual markings of dermatoglyphics, which are visible to the naked eye, are described as "continuous and discontinuous alternating ridges and sulci" (Montagna and Parakkal 1974:10), similar to the markings or the stripes on a zebra.

Fingerprint Analysis for Identification and Authentication

Dermatoglyphics have long been used as a tool in the identification of unknown individuals. Many attributes of dermatoglyphics make them useful in this regard. Four important factors about fingerprints make them valuable for personal identification (Holt 1968). Most importantly, fingerprints are not affected by age. They are also not affected by environment, except during in utero development. Their high variability and the fact that their patterns are so easily classified are also important characteristics of dermatoglyphics that contribute to their use for personal identification and other biological studies (Holt 1968:6).

Fingerprints are cheap and easy to obtain, which make the data easily available and quite abundant. This enables a researcher to gather a large sample fairly quickly and practically, and makes possible routine use by law enforcement agencies. An individual's fingerprints are typically recorded by taking an impression on one of various materials. The method used most commonly by law enforcement and scientists is the ink and paper method.

This method produces prints that are legible, with good detail, and ready for comparison. The finger is coated with a thin layer of black ink and then pressed and rolled (in order to obtain a complete print) from one side to the other, on a piece of glossy paper. Due to the fact that ridges are elevated, a print is left behind which records the details of the pattern on that particular finger.

There are other less common, inkless techniques for recording fingerprints as well. For instance, a finger may be coated with a chemical and then printed on a piece of paper. The paper has been treated previously with another chemical that makes the print appear. In other cases, the paper is sprayed with a chemical that develops the print (Cowger 1983). Another method for recording finger prints is to dust the fingers with a powder that is usually intended for use with latent prints, and then to lift the print from the finger with an adhesive material which is then placed against an opaque background (Cowger 1983). This however, produces a backward or reversed image of the print unless it is viewed through a transparent backing. Recently, some law enforcement agencies have moved toward digital scanning of finger prints which downloads the print directly into a computer data base.

In many instances, latent prints, or impressions of fingerprints accidentally left behind when a finger has normal contact with most surfaces, are found at a crime scene. There are three different types of prints which are found at crime scenes (De Forest, Gaensslen and Lee 1983:341). Visible prints are left by a finger stained with a colored material such as blood, dirt or grease. Plastic prints, or impressions made by pressing on a soft surface such as wax or clay, can also be found at a crime scene. Finally, latent prints, which are not easily visible, are often left behind on smooth surfaces. These prints must be visualized with various techniques such as dusting with a powder, argon laser illumination, and the use of silver nitrate (De Forest, Gaensslen and Lee 1983:332).

Fingerprint matching is a reliable and widely used technique for personal identification or verification. In particular, an increasingly common approach to identification involves scanning a sample fingerprint or an image thereof, converting it into electrical signals, and storing the image and/or unique characteristics of the fingerprint image. The characteristics of a sample fingerprint are then compared to information for reference fingerprints already in storage to determine or verify the identity of the individual providing the print. Devices employing such methods are being increasingly deployed as an element of security and access control systems.

Fingerprints are typically classified into a plurality of discrete sets and/or subsets in the form of a hierarchical tree to expedite searching. In 1901, Sir Edward Henry formulated a system of classification which enables prints to be quickly classified and easily located in a file (De Forest, Gaensslen and Lee 1983). This is the most widely used method in the United States for classifying finger prints (Cowger 1983). This method relies mostly on the finger print patterns themselves. Their corrugated markings had been previously classified by Sir Francis Galton in the late 1800s, into 3 major pattern types; loop, arch, and whorls (Galton1965 [1895]). These three basic patterns have been further divided into eight subpatterns (De Forest, Gaensslen and Lee 1983:332). Today, a common top level classification for fingerprints usually differentiates the prints into the classes of: plain whorl, plain loop, tented arch, etc. based upon broad ridge pattern types. These classes are further divided into subclasses. A fingerprint sample to be searched, once classified, can be more efficiently compared to only those prints in the respective classes and subclasses of the search tree. For example, see U.S. Pat. No. 5,465,303 to Levison *et al.* which describes both the widely used Henry classification system and the Vucetich classification system.

The size of law enforcement fingerprint databases, and the growing difficulty of manual classification and searching, has led workers in the field to develop many automated

systems and methods for fingerprint analysis, classification, and matching. Most approaches to classification and matching focus on the unique pattern of ridges on an individual's fingertips, rather than on the ridges themselves.

U.S. Pat. No. 5,140,642 to Hsu *et al.* (incorporated herein by reference in its entirety) is directed to a method for determining the actual position of a core point of a fingerprint based upon finding ridge flows and assigning a direction code, correcting the ridge flows, and allocating the core point based upon the corrected direction codes.

U.S. Pat. No. 5,040,224 to Hara discloses an approach to preprocessing fingerprints to correctly determine a position of the core of each fingerprint image for later matching by minutiae patterns.

U.S. Pat. Nos. 3,859,633 and 3,893,080 both to Ho *et al.* (both incorporated herein by reference in their entirety) are directed to fingerprint identification based upon fingerprint minutiae matching.

U.S. Pat. No. 3,959,884 to Jordan *et al.* (incorporated herein by reference in its entirety) discloses a method of classifying fingerprints by converting a fingerprint to a pattern of binary values which define a spatial array of ridges and valleys, and constructing a descriptor code from the binary values.

U.S. Pat. No. 4,151,512 to Riganati *et al.* (incorporated herein by reference in its entirety) describes a fingerprint classification method using extracted ridge contour data. The ridge flow in the fingerprint pattern and minutiae data are identified and extracted from a fingerprint pattern. Topological data are extracted from the ridge contour data, and the extracted information is used to automatically perform classification of the fingerprint patterns and/or matching of the fingerprint pattern.

U.S. Pat. No. 4,185,270 to Fischer *et al.* (incorporated herein by reference in its entirety) discloses a process for encoding and verification based upon minutiae. U.S. Pat. No.

4,210,899 to Swonger *et al.* (incorporated herein by reference in its entirety) discloses an optical scanning fingerprint reader cooperating with a central processing station for a secure access application such as admitting a person to a location or provide access to a computer terminal. U.S. Pat. No. 4,525,859 to Bowles (incorporated herein by reference in its entirety) is also directed to minutiae matching and describes an automated system. U.S. Pat. No. 4,947,443 to Costello (incorporated herein by reference in its entirety) discloses a method for verifying the identity of a person using four of six characteristics.

Another approach to fingerprint matching attempts to assign a unique digital code to each fingerprint. U.S. Pat. No. 4,747,147 to Sparrow (incorporated herein by reference in its entirety) discloses a fingerprint scanning system and method for rotating a scan line about a central point on the fingerprint. A code representing the types of irregularities is recorded, along with a ridge count so that coordinates give a complete topological and spatial description of a fingerprint for computer processing.

U.S. Pat. No. 5,363,453 to Gagne *et al.* (incorporated herein by reference in its entirety) relates to a system and method for generating a numeric fingerprint identifier for inclusion on a magnetic strip.

U.S. Pat. No. 5,239,590 to Yamamoto (incorporated herein by reference in its entirety) discloses a fingerprint image processing method wherein a master and a sample fingerprint image are divided into a plurality of pixels with an associated direction. The direction of each pixel is determined based on pixel density partial differentials between the pixel and adjacent pixels for a plurality of directions.

U.S. Patent 5,974,163 to Kamei (incorporated herein by reference in its entirety) describes a fingerprint image classification system employing "classification units" each of which generates a probability data set indicating the probability of a fingerprint image being

classified into various categories; and a category decision unit for outputting a classification result according to the probability data set.

U.S. Patent 5,974,162 to Metz *et al.* (incorporated herein by reference in its entirety) describes a device for forming and detecting fingerprint images, and a compact system for detecting the surface topography of the finger of an individual and producing images which can be electronically stored or transmitted..

U.S. Patent 6,005,963 to Bolle *et al.* describes a system and method for determining if a fingerprint image contains an image portion representing a partial fingerprint impression, involving dividing a fingerprint image into blocks of pixels.

U.S. Patent 6,021,211 to Setlak *et al.* (incorporated herein by reference in its entirety) describes a method and apparatus for indexing and searching reference fingerprints to determine if a sample fingerprint matches one of the reference fingerprints, which involves determining "index values" for the reference fingerprints and the sample fingerprint, based upon ridge flow curvature of the fingerprints.

Presently, there are large data bases with vast numbers of fingerprints kept on file with such agencies as the United States FBI, and military and other law enforcement agencies. In order to match a recovered print from a crime scene to an individual, however, that individual's prints must already be on file. This is not always the case.

Measurement of Ridge Width

Some previous studies measured the number of ridges found in a one centimeter area (Cummins and Midlo,1961:272; Holt, 1968:27). In the early 1900s, Sir Francis Galton counted the number of ridges within a one centimeter line beginning at a triradius. This method excluded any finger print with a pattern such as an arch which does not have a triradius (Galton 1965). Therefore, Galton's method was affected by pattern type as well as ridge breadth. Kristine Bonnevie (1924), studying finger prints and inheritance, used a

technique similar to Galton's which, however, she altered to consider all pattern types. Bonnevies' method consisted of counting the, "number of ridges which cut or touch a straight line running from the triradius to the core or center of the pattern" (Holt 1968:40). Although this method includes finger prints regardless of the pattern type, a triradius or a core, which is part of a pattern type, is still employed and therefore pattern is still a variable in that it dictates where the measurement should begin.

Similarly, in a study by Ohler and Cummins, "An indirect method was used in the determination of ridge breadth, the number of ridges crossing transversely a line 1.0 cm. in length being counted" (1942:342). Eventually, an average ridge count was recorded as being the mean of these measurements for all ten fingers as were measurements from ten palmar areas. Ohler and Cummins obtained the average ridge breadth of an individual by dividing the mean ridge count of ridges per centimeter into 1.0 cm.

A more recent study by Hall and Kimura (1994), employed the Total Ridge Count (TRC) method. Initially, the Henry classification system (Holt 1968) was used to locate a triradii. Then, with a Henry glass, (also invented by Henry in the late 1900s) which consisted of a magnifier glass with a 1.0 centimeter line etched in it, was used to aid the count. The line was used to join two points and all of the lines which intersect this were counted. Once again, the TRC method excluded fingers which had a pattern with no triradii point. Many other studies employed Total Ridge Count which seems to be the predominant method used in past studies (Demarchi, Giordano, and Marcellino 1997; Micle and Kobyliansky 1986; Loesch, Lafranchi, and Ruffolo 1990; Buchi 1978; Leguebe and Vrydagh 1981). Another study by Mi, Budy, and Rashad (1982) employed the Finger Ridge Count defined as, "the number of dermal ridges intersecting a straight line drawn from the central point of a triradius to the core of an adjacent pattern" (1982:286). Therefore, a finger pattern containing multiple triradii had multiple measurements. They then went on to state that their definition of TRC was the sum

of the measurements from all ten fingers, using the largest of the measurements when there were multiple ones. Further, they defined Absolute Ridge Count as being the sum of all the measurements total, no matter how many each finger had (Mi, Budy and Rashad 1982).

Measuring ridges across a transverse 1.0 cm line dominates the literature in studies on ridge breath analysis (Cummins, Waits, and McQuitty 1939; Cummins and Midlo 1961). Other isolated studies employed methods that have not been duplicated in the literature, such a Mean Ridge Breadth (MRB) coined by David (1981) and not clearly defined in his article. In addition, although only somewhat related, many studies on sex and ridge breadth correlation used the ridges on the palm instead of, or in conjunction with, those on the finger tips (Floris 1975 ; Loesch and Lafranchi 1990; Cummins and Midlo 1926;). The present study is concerned with only the measurements on the fingertips.

Dermatoglyphics and Gender

Although fingerprint analyses have been applied to human identification in forensic anthropology and to population studies within the field of physical anthropology (De Forest, Gaensslen and Lee1983; Jantz and Chopra 1982; Kamali, Mavalwala, Khaneqah and Bhanu 1991), the research that has been done using fingerprints to determine an individual's sex has neither been conclusive nor has there been any consistency among the different approaches.

David (1981) suggested that the larger dermatoglyphic measurements seen in males may be related to stature. Cummins, Waits and McQuitty (1941) pioneered a study which attempted to correlate ridge breadth in digits and palms with body size. Their sample consisted of males only, and the measurements used were derived by counting the ridges crossing a 1.0 cm transverse line, which differs from the method of this invention. The subjects were grouped in incremental classes by height and weight. The study concluded that "Ridge breadth varies directly, but in very loose correlation, with body weight, stature, hand length, hand breadth and digital breadth" (1941:147).

Cummins and Midlo (1961) also concluded that there was a loose correlation between ridge breadth and body size. This study, however, clearly questions whether the fact that females smaller bodies, and therefore smaller hands, might account for their ridges being narrower than those of males, or whether this is indeed a direct genetic correlation. Rothhammer, Llop and Neel (1982) also found small but significant correlations between dermatoglyphics and an individual's physique.

Ohler and Cummins (1942) determined that there was some correlation between hand size and ridge breadth, however, the links were not strong enough to be considered very significant. In a supplemental check of the same study, selected males and females with the same size hands were measured. They found that the female ridges were over 10 percent smaller than those of the males. The latter study suggests that obviously something other than hand size was influencing the difference in ridge breadth dimensions between males and females.

It is very clear in the dermatoglyphic literature that, regardless of hand size, males have wide, coarse ridges and females have narrow, fine ridges (Mi, Budy and Rashad 1982; Cummins and Midlo 1961; Holt 1968; Cummins 1964; Montagna and Parakkal 1974; Meir, Goodson and Roche 1987; Floris 1975). It has also been noted that males and females tend to have different pattern type frequencies (Micle and Kobyliansky 1988; Holt 1968; Mi, Budy and Rashad 1982; Dankmeijer 1938; Holt 1968). Since no pattern is unique to a particular sex, pattern type or the frequency of a pattern on a fingerprint alone, can not be used to determine the sex of an individual.

Micle and Kobyliansky (1986) used over 66 different variables including pattern indices, palmar ridge counts, pattern size and symmetry to develop a discriminate function for predicting sex. They were able to correctly classify 71.6 percent of their subjects by sex. However, a method employing 66 variables is too cumbersome for routine use.

In 1997, Demarchi, Giordano and Marcellino embarked on a study using dermatoglyphics to examine interpopulation relationships. Many features were analyzed, including finger ridge count, palmar ridge count, and pattern intensity indices for finger and palms. Males and females were included to examine the sexual differences as well. They determined that there were significant statistical differences between the sexes for the frequency of most of the variables, but did not develop a technique for predicting sex from dermatoglyphic traits.

Despite a proliferation of attempted fingerprint classification and automated searching approaches, and despite past observations of dermatoglyph-gender correlations, there still exists a need for reliable, rapid, and preferably automated fingerprint analysis to determine the probable gender of an individual. No previous workers have provided a method which can be used to predict an individual's sex based on a fingerprint. The present invention provides such a method, and accordingly will have applications in fields such as forensic anthropology and law enforcement.

BRIEF DESCRIPTION OF THE INVENTION

It is apparent that techniques, and even definitions of the same technique, for measuring ridge width have varied among different practitioners. Not only does there need to be some consistency, but a new technique is needed which will address many of the shortcomings of the past methods. No previous study has measured up to ten parallel ridges regardless of the pattern type. In addition, most other methods controlled their measurements within a 1.0 cm area. The method employed in the present invention allows for ten ridges to be measured which then define their own size, rather then requiring the practitioner to subsequently fit ridges into a pre-prescribed area. It is suspected that this method will prove simple to use and will be easily reproducible.

The invention provides a method of determining the probable sex of an individual from measurement of one or more fingerprints from that individual. It has previously been observed that there is a correlation between ridge width measurements and sex, however it was not at all clear from previous studies that one could expect these differences to provide a useful means of determining gender from a single print or set of prints. Ridge width is ignored or even deliberately factored out in many classification schemes, see for example US 6,005,963 to Bolle *et al.* Prior to the present invention no predictive model has been capable of discerning between males and females. Functions are provided by the invention to accurately predict the sex of an individual based on their finger tip ridge breadth measurements.

The analysis indicates that finger tip ridge breadth is indeed correlated to sex. The ability to predict an individuals sex, based on a finger tip ridge breadth measurement can be accurately done with the use of a specific formula created for that purpose. In addition, the fingerprint does not need to be complete, as long as multiple unobstructed parallel ridges, preferably about ten such ridges, are present. Finally, the specific finger the print comes from does not need to be known, this method can be applied to prints from unknown digits.

It is an object of this invention to provide a new tool for the fields of forensics, forensic pathology, forensic anthropology, and law enforcement, by making it possible to narrow down the search for an unidentified individual based on the probable sex of the individual, based on one or more fingerprints recovered at a crime scene. It is a specific object of the invention to provide methods for correlating fingerprint ridge width with gender.

BRIEF DESCRIPTION OF THE FIGURE

Fig. 1 shows a typical fingerprint, with the straight line representing an example of a measurement across ten parallel ridge lines with no obstructions.

DETAILED DESCRIPTION OF THE INVENTION

The invention utilizes the average measurements from a sample of 500 individuals to create and test a discriminant function for predicting sex based on finger tip ridge widths. Average measurements from a larger sample would obviously provide an even more statistically robust model.

The invention is concerned with measurements of the fingertips only. As noted above, it is obvious that the definitions of the same techniques vary among the different practitioners. Although different systems of measurement have been used to study ridge breadth in the past, the present invention employs the technique of measuring across multiple parallel ridges, preferably between two and ten ridges. No previous technique has measured multiple parallel ridges regardless of the pattern type. In this study, the pattern type was considered independent of measurement and therefore would not affect the measurement. Every finger was measured regardless of pattern. Previous methods did not measure every finger because certain patterns lack a triradii or a core, which is part of the measurement when pattern is considered (Galton 1965; Bonnevie 1924; Mi, Budy and Rashad 1982). The particular embodiment of the invention described here focuses on ridge breadth and its relationship to sex, with pattern and other factors being ignored.

The method is advantageous because of its intended use in the field of forensic science. Many times there is only one fingerprint left at a crime scene. If that print happens to be an arch pattern, many previous methods (Hall and Kimura 1994; Galton 1965[1892]; Holt 1968) would not have permitted a measure of ridge breadth because the pattern does not contain a triradii. Regardless of the pattern type, the method proposed here can be employed on any fingerprint as long as it is readable, even on partial prints where the pattern may not be discernable, as long as there are multiple, and preferably two to ten, parallel ridges present.

All of the measurements in the examples were made using exactly ten parallel ridges. It is anticipated that the method would be useful, if perhaps less accurate, if fewer than ten ridges are measured in a print to be analyzed. Many latent prints left behind at crime scenes are only partially recovered, and quantitative statistical studies using this method, but measuring fewer than ten parallel ridges, are obviously desirable. It is, however, anticipated that multiple measurements of fewer than ten parallel ridges could be combined. Measurement of, for example, two separate instances of five parallel ridges could be combined with little or no loss of accuracy.

In developing the embodiment of the invention exemplified below, ten parallel ridges with no obstructions were measured on every finger of 500 individuals, 250 males and 250 females, and the results were summed for each individual.

Since the object of the invention is to determine, from a finger tip's ridge breadth, the gender of an individual, many of the tests run were done separately for each sex. Therefore, both cumulative data and data for each of the sexes are presented. The sexes were equally represented, with 250 of each present. While the race of each individual was recorded, the extent of the disparity in sample size between the groups was such (81.6 percent were white) that it was decided to not include the race variable in this analysis. The overall mean summed measurement of all ten fingers for the male sample alone is 5.58 cm with a standard deviation of .378 cm. The overall mean summed measurement for all of the fingers combined in the female sample was 4.44 cm with a standard deviation of 0.31 cm. When comparing the results between the sexes, it is apparent that there is a 1.14 cm difference between the means for the averages of all ten fingers between the males and the females. The results from a two tailed Independent Sample T-Test indicate that there is a significant difference in male and female means for the average of all ten fingers, $t(498)=36.256$, $p.<0.001$. According to a Pearson's

bivariate correlation, sex had the strongest correlation with ridge breadth followed by the variables height and weight, respectively.

The next procedure performed was a Partial F test. This method was used to determine the strength of an independent variable in predicting the dependent variable, when taking into consideration the other variables already in the model. Ridge breadth was used as the dependent variable, and a full model regression analysis was performed using sex, height, and weight as the independent variables. Subsequently, three reduced models were performed, each one excluding one of the independent variables. When the results were put into the appropriate formulas (Neter, Wasserman, and Kunter 1990), it was concluded that weight was a useful predictor of ridge breadth, $F=15.59$ (1,496), $p.<0.001$. It was also concluded that sex was a useful predictor of ridge breadth, $F=596.33$ (1,496), $p.<0.001$. In other words, weight and sex made significant contributions on their own, even when all of the other variables were included. However, it was discovered that height, although previously a bivariate correlation with ridge breadth, was not a useful predictor of ridge breadth, when the other two variables, sex and weight, were already in the model. Its individual contribution with the other variables was not significant.

The final procedure performed was a discriminant analysis. In this study, a discriminant analysis was employed to develop a function that will enable one to predict group membership. Formulas were developed for each of the ten fingers, however, for this specific study, the individual's average for all ten fingers was used since all of the fingers were highly intercorrelated with each other and it is usually not known which finger leaves the print behind. It has already been noted by Holt (1959) that all of the fingers are correlated with one another. The highest correlations found were between adjacent fingers and homologous fingers (Holt 1951; Holt 1959).

According to the discriminant analysis, 94.4 percent of the randomly selected group of males and females were correctly classified according to sex, while 94.8 percent of the validation group was correctly classified. This latter result is slightly better than the initial result, and both results are remarkably greater than chance, which would have correctly classified approximately 50 percent of the cases. However, these results were derived from using the ten finger average measurement. Since it is very difficult to determine which specific finger a latent fingerprint comes from, the data suggest using the formula created for the ten finger average measurement if the specific finger is unknown. Of course, if the finger or fingers can be determined, then that specific formula or the formula for that hand average would be more appropriate. However, when a partial or isolated print from an unknown finger is found, the formula chosen for determining the sex of that individual should be the ten finger average formula.

Since the previous test run to determine the accuracy of these functions tested the specific functions with their corresponding finger measurement, the accuracy of a print from an unknown finger is still not known. Therefore, a subset of 60 individuals, thirty males and thirty females, was chosen randomly from the original 500 individuals to test that specific scenario. Since the exact finger of an isolated print is usually not known, all ten finger measurements taken from each of the 60 individuals were used in both the male and the female formulae created for the ten finger average. The formula for the ten finger average was chosen to be used in this test procedure because it is the most accurate of all of the formulas. In addition, this formula was created using the average measurements of all of the fingers of both hands, generating a result that averages out deviant or aberrant measurements. This final test was run so that a print, from any finger, found at a crime scene, will have a predicted accuracy based on the ten finger average formula. Each of the ten finger measurements of every individual was used for both the male and female formulas for the ten finger average; those correctly classified

were calculated together for predictive purposes. The results are as follows: the percentage correctly classified using the ten finger average formula for the males R1 was 87%, R2 was 97%, R3 was 87%, R4 was 73%, L1 was 100%, L2 was 97%, L3was 80%, l4 was 77% and L5 was 57%. The percentage correctly classified using the formula for the ten finger average for the females was R1 83%, R2 was 77%, R3 was 87%, R4 was 93%, R5 was 93%, L1 was 87%, L2 was 76%, L3 was 100%, L4 was 90% and L5 was 90%. The overall lowest score predicted for the male sample was at 57% on L5, while the lowest predicted score for the females was 76% on L2. Both the males and females had a finger with a predicted score of 100%, L1 and L3 respectively. Regarding the females, their overall accuracy for predicting sex, using the ten finger average formula applied to each specific finger and then combining the results, was 87.3%. Using the male sample, the overall score for all of the fingers combined, predicting sex using the formula for the ten finger average with each individual finger measurement was 82.0%. What this illustrates is, if a random fingerprint from an unknown finger is found, using the formula created for the ten finger average, one could predict the sex of the individual accurately between 76% and 100% of the time for an average correct classification of 87.3% for females. For males, the correct classification of sex from an unknown digital print could be between 57% and 100% of the time with an average correct classification of 82%. This result is significantly better than chance which could only predict accurately the sex of an individual 50% of the time.

Thus, the invention provides a method of determining the probable sex of an unknown individual, said method comprising the step of measuring the ridge width in one or more of said individual's fingerprints.

In another embodiment, the ridge width is measured by measuring the overall width of a plurality of parallel ridges.

In another emodiment, the ridge width is measured by measuring the overall width of from two to ten parallel ridges.

In another embodiment, the method further comprises the step of comparing the measured ridge width to a data compilation which correlates ridge width with probable gender. In a further embodiment, the step of comparing the measured ridge width to the data compilation is carried out by means of a computer, which outputs the probable gender. In yet another embodiment, the measurement of ridge width is carried out by a process of computerized image analysis.

And in yet another embodiment, the method comprises the steps of

(a) calculating the result P_m of the male formula $P_m = A_m x - B_m$, wherein

(i) x is the sum distance in centimeters, either measured or extrapolated, across 100 fingerprint ridges,

(ii) A_m is 43 (± 5%), and

(iii) B_m is 120 (± 5%); and

(b) calculating the result P_f of the female formula $P_f = A_f x - B_f$, wherein

(i) x is the sum distance in centimeters, either measured or extrapolated, across 100 fingerprint ridges,

(ii) A_f is 34 (± 5%), and

(iii) B_f is 75 (± 5%) (the female formula);

and if $P_m > P_f$, determining that the individual is probably male, and if $P_f > P_m$, determining that the individual is probably female.

The invention also encompasses a device comprising an image analyzer component which displays an image of the fingerprint of an individual, further comprising a means for inputting to the analyzer the coordinates of a line segment normal to a plurality of parallel fingerprint ridges, wherein said device computes the length of the line segment and computes the

probable gender of the individual. Also encompassed by the invention is a data compilation which correlates fingerprint ridge width with probable gender, which may be visually readable or in computer-readable format. Finally, the invention encompasses a computer-readable medium, carrying the data compilation.

In sum, the invention provides a method of predicting the probable gender of an individual based on a measurement of the individual's finger tip ridge breadth. Therefore, when a fingerprint is recovered which does not match any already on file, the method of the invention should help narrow down the search to the correct sex of that individual between 82.0 and 87.3% of the time.

EXAMPLES

The fingerprints used in this study were obtained from the Butte County Sheriff's Department records of individuals arrested in Butte County, California during 1998. The sample itself is comprised of fingerprint sets from 500 individuals: 250 males and 250 females. Each set of prints includes a set of rolled fingerprints for each of the ten individual fingers as well as a set of the flat right and left fingers taken simultaneously, with the thumbs printed separately. According to Holt, "It is important to have flat, as well as rolled impressions, of the fingers. They provide a check when the identity of any rolled print is in doubt" (1968:32). The set of rolled fingerprints was taken in the standard method described by others (Cowger 1983; Cummins and Midlo 1961; Galton 1965[1892]): inking the finger and then rolling the finger from one edge to the other. For the second type of print, the fingers again were inked, but instead of being rolled from one side to the other individually, the fingers were printed simultaneously in a flat, pressed fashion. Thus, each data sheet of fingerprints consisted of two prints for each of the ten digits. Additional information recorded on the same data form consisted of sex, race, height, and weight. All of the individuals used in this study were adults, aged 18 or older. Though fingerprints do not change their pattern or

structure throughout an individual's life, they do grow in size as an individual grows (Loesch 1983: 139). Thus, the limitation of the sample to adults eliminates potential spurious data stemming from juvenile fingerprints.

An OLYMPUS SZ4045TR ™ Zoom Stereo Microscope and a UNISLIDE ™ mechanical positioner (Velmex Inc., Bloomfield, N.Y.) were used to view the fingerprints. An ACU-RITE III ™ digital readout system (Bausch & Lomb, Rochester N.Y.) was used to measure the ridges in millimeters. The increment being measured consisted of ten parallel ridges within the fingerprint.

Some previous studies measured the number of ridges found in a one centimeter area (Cummins and Midlo,1961:272; Holt, 1968:27). The technique of measuring ridges across a transverse 1.0 cm line dominates the literature in studies on ridge breath analysis (Cummins, Waits, and McQuitty 1939; Cummins and Midlo 1961). The method employed in the present invention allows for ten ridges to be measured which then define their own size, rather than requiring the practitioner to fit ridges into a preprescribed area. It is anticipated that this method will prove simple to use and will be easily reproducible.

First, the data sheet was placed under the microscope, then the ten ridges to be measured were aligned perpendicular to the X-axis in the eye piece. Viewing the print under high power allowed the analyst to find ten parallel ridges with no obstructions or intervening digital minutia. The actual spot chosen for counting was random, being the first spot noted to have ten parallel ridges with no bifurcation or other minutia which would cause a break in the line perpendicular to the ridges chosen for measure. Bifurcations, where ridges divide into two, and anomalies inconsistent with ten parallel ridges were considered obstructions and were avoided.

The measurement began in a 'valley', halfway between two ridges, as shown in Figure 1. After counting over ten ridges, the measurement ended again, mid-valley. The increment

machine was scrolled perpendicular to the angle of the ridge lines, measuring the ridges in millimeters to a precision of 0.0001 mm. All of the measurements were taken from the first set of rolled fingerprints. If a fingerprint was smeared, too light, not fully printed or in any way unreadable, the measurement was taken from the second set of 'plain impressions', or flats, on the same record form. If neither of the fingerprints was deemed readable for a ten ridge measurement or the finger was not present due to amputation, no measurement was recorded. All ten fingers for each individual were measured. Only individuals with 7 or more readable prints were included in this study.

Statistical Methods

The information on the data sheet was then entered into a data base developed with the Statistical Package for the Social Sciences (SPSS) version 7.5 (SPSS 1996). The individual's height and weight, along with the measurements for each finger as well as the averages for the right hand alone, the left hand alone, and the average for all ten fingers for each individual was recorded in the data base. When a measurement was missing due to it being unreadable or due to amputation, the average was figured with one less measurement.

Since the ultimate hypothesis in this study was to create a discriminant function to predict the sex of an individual, it first needed to be determined if there even was a difference between the male and female ridge breadths. A T-Test was executed to compare the means between the male and female ridge breadth measurements for each of the ten digits as well as the male and female averages. Correlations were performed to assess whether or not any of the variables such as height and weight were related and to what degree. A Partial F-Test was performed in order to eliminate any variables that did not make a significant contribution to the final stage of the study. Subsequently, a discriminant analysis was performed in an attempt to accurately predict group membership by sex. Eventually, a subgroup of the population consisting of 60 individuals, 30 males and 30 females, was used to test the

discriminant function's accuracy based on one of the formulas developed. It is most typical to have one isolated latent fingerprint submitted for identification, however, it is most likely that the specific finger this print comes from will not be known. Therefore, the most accurate formula developed, the one for the average of ten fingers combined, was tested using all ten of the individual finger measurements separately, to test the formula's accuracy when used with an isolated single finger measurement.

A measurement, in centimeters, was recorded by the process described above, for each finger of every individual. A right hand average, a left hand average as well as a general average of all ten fingers was also calculated for each individual. Table 1 illustrates the overall mean width for ten ridges for all of the fingers combined, both sexes included, was 5.01 cm with a standard deviation of 0.67 cm. The mean for the right hands for all 500 cases was 5.06 cm with a standard deviation of 0.67 cm. The result for the mean of the left hands was 4.96 cm with a standard deviation of 0.69 cm. When all of the individuals were analyzed together, the finger with the largest mean measurement was the right thumb with a mean of 5.36 cm and a standard deviation of 0.82 cm. The finger with the smallest measurement was the left ring finger with a mean of 4.77 cm and a standard deviation of 0.77 cm.

Table 1.
Mean Width of Ten Ridges for the Combined Sexes.

	Number of Indiv.	Mean	Std. Deviation
Average of all 10 fingers	500	5.01cm	0.67cm
Right Hand Averages	500	5.06cm	0.67cm
Left Hand Averages	500	4.96cm	0.69cm

The overall mean measurement of all ten fingers for the male sample alone is 5.58 cm with a standard deviation of .378 cm. The mean for the right hand was 5.61 cm with a standard deviation of 0.41 cm, while the mean for the left hand was marginally smaller at 5.54 cm with a standard deviation of .396 cm, as illustrated in Table 2. In the male sample, the

right thumb was once again the finger with the largest mean measurement at 5.94 cm with a standard deviation of 0.65 cm. The finger with the smallest measurement among the male sample was the left pinky, with a mean of 5.31 cm and a standard deviation of 0.55 cm; this was a different result than obtained in the combined sex sample. The single smallest measurement for the males was 3.74 cm and the single largest male measurement was 7.89 cm.

Table 2.
Mean Width of Ten Ridges for Males Only

	Number of Indiv.	Mean	Std. Deviation
Average of all 10 fingers	500	5.58cm	0.378cm
Right Hand Averages	500	5.61cm	0.41cm
Left Hand Averages	500	5.54cm	0.396cm

The overall mean measurement for all of the fingers combined in the female sample was 4.44 cm with a standard deviation of 0.31 cm. The mean for the average of the right hand measurements was 4.51 cm with a standard deviation of 0.35 cm. The mean for the average of the left hand fingers was 4.37 cm with a standard deviation of 0.34 cm, as illustrated in Table 3. Similar to the results of the sexes combined, the finger with the smallest average mean among the females was the left ring finger, at 4.21 cm with a standard deviation of 0.48 cm. The finger with the largest average measurement was also the right thumb with a mean of 4.77 cm and a standard deviation of 0.51 cm. The smallest individual measurement of the female fingers measured was 2.93 and the largest female measurement recorded was 6.72 cm.

Table 3.
Mean Width of Ten Ridges for Females Only

	Number of Indiv.	Mean	Std. Deviation
Average of all 10 fingers	500	4.44cm	0.31cm
Right Hand Averages	500	4.51cm	0.35cm
Left Hand Averages	500	4.37cm	0.34cm

When comparing the results between the sexes, it is apparent that there is a 1.14 cm difference between the means for the averages of all ten fingers between the males and the females. In order to see if this difference is significant, a T-Test was executed to compare the means between the male and female ridge breadth measurements. If no distinction was found, there would be no justification for continuing on with a discriminant function using these variables. Table 4, which lists the results from a two tailed Independent Sample T-Test, illustrates that there is a significant difference in male and female means for the average of all ten fingers, $t(498)=36.256$, $p.<0.001$. The same test was performed to compare the means of the left hands and again to compare the means of the right hands between males and females. Again, the results were highly significant, for the left hand, $t(498)=35.596$, $p.<0.001$ and for the right hand, $t(498)=32.392$, $p.<0.001$. It should also be noted that the smallest female measurement was in the 2-3 cm range while there were no actual male measurements in that range. In conjunction with this, the largest male measurement was in the 7-8 cm range and there were no female measurements in this range.

Table 4.
Independent Sample T-Test for Equality of Means

	T Result	Degrees of Freedom	Significance (2-tailed)
Average of all 10 Fingers	36.256	498	.000
Right Hand	35.596	498	.000
Left Hand	32.392	498	.000

Before evaluating a correlation between finger ridge breadth and sex, it was necessary to determine whether there was a significant relationship between any of the primary variables such as sex, height, weight, and ridge breadth. The effect of race could not be measured due to the make-up of the sample. Initially, a Pearson's bivariate correlation analysis was performed on all of the variables mentioned above. The results of this indicated a strong

relationship between all four of the primary variables. All of the correlations had p-values <0.001. This indicated that there was a high intercorrelation between all of the variables. Since Pearson's *r* correlation coefficient is an index of the strength of the association between two variables, it was possible to rank which variables more strongly covary with ridge breadth. Sex had the strongest correlation with ridge breadth followed by height and weight, respectively.

The next procedure performed was a Partial F test. This method was used to determine the strength of an independent variable in predicting the dependent variable, when taking into consideration the other variables already in the model. Ridge breadth was used as the dependent variable, and a full model regression analysis was performed using sex, height, and weight as the independent variables. Subsequently, three reduced models were performed, each one excluding one of the independent variables. When the results were put into the appropriate formulas (Neter, Wasserman, and Kunter 1990), it was concluded that weight was a useful predictor of ridge breadth, $F=15.59$ (1,496), $p.<0.001$. It was also concluded that sex was a useful predictor of ridge breadth, $F=596.33$ (1,496), $p.<0.001$. In other words, weight and sex made significant contributions on their own, even when all of the other variables were included. However, it was discovered that height, although previously a bivariate correlation with ridge breadth, was not a useful predictor of ridge breadth, when the other two variables, sex and weight, were already in the model. Its individual contribution with the other variables was not significant. Therefore, the remaining analyses performed concentrated on the variables sex, weight and ridge breadth, as height had then been determined unnecessary.

The final procedure performed was a discriminant analysis. In this study, a discriminant analysis was employed to develop a function that will enable one to predict group membership as well as determine which variables were most useful for that prediction. A discriminant analysis is used to classify observations into two groups, in this case male and

female, given that there is an existing sample that falls into known groups. In other words, with information from an existing sample of cases, a prediction is possible, with a certain amount of accuracy, to which group a new case will belong. In order to compensate for the optimistic bias in "success of classification", due to the fact that the classified cases are the same ones used to estimate the coefficients of the classification function, a cross validation procedure was employed.

Essentially, 50 percent of the original data, or 250 cases, were randomly selected by the computer and used to compute the classification functions. The other 50 percent were employed later as the validation (i.e., test) set to verify the accuracy of the success of the classification. To classify cases, a Fisher's classification function was determined for each group, male and female.

Presentation of Results Used to Classify an Individual by Sex

Predicted group membership for a case is determined by the value of the Fisher's classification function, with a case being placed in the group that represents the classification function of the largest value. In other words, a measurement from a finger print of an unknown individual can be inserted into the two formulae developed. One formula predicts female classification and the other predicts male classification. When the measurement is inserted into the formulae and the numbers are calculated out, whichever function results in a larger number is the classification sex of that finger print. For instance, the classification function for the male group was $42.823x-120.124$, while the classification function for the female group was $33.868x-75.395$, as illustrated in Table 5. When using a finger ridge breadth measurement from an unknown individual as an indicator of sex, the measurement for the width of ten parallel ridges was substituted for x in each function.

Table 5.
Fisher's Classification Function Coefficients for Sex
Using The Ten Finger Averages.

	Male	Female
Individual averages with all ten fingers	42.823	33.868
(Constant)	-120.124	-75.395

For this specific study, the individual's average for all ten fingers was used since all of the fingers were highly intercorrelated with each other and it is usually not known which finger leaves the print behind. It has already been noted by Holt (1959) that all of the fingers are correlated with one another. The highest correlations found were between adjacent fingers and homologous fingers (Holt 1951; Holt 1959).

The following is an example to help illustrate how this function works. Individual number 27 had an average ridge breadth value of 6.223 cm across all ten fingers. This measurement is then inserted into both the male and the female functions. When applying the male function, we multiply 42.823*6.223 and subtract 120.124, for a result of 146.3635. Using the female function we multiply 33.868*6.223 and then subtract 75.395, for a result of 135.3656. Since 146.3635, the result from the male function, is a larger result than 135.3635, the result from the female function, then individual number 27 was predicted to be a male, which it was. The greater value is always the group in which that case is predicted to belong.

Thus, if x is the sum distance across 100 ridges for the individual fingerprint (either measured for ten fingers, or extrapolated to 100 ridges from a lesser measurement), the formula Ax – B generates a predictive number for each sex, where for the male formula A is about 43 and B is about 120, and for the female formula A is about 34 and b is about 75. If the male formula generates the larger value, the individual is predicted to be male, if the female formula generates the larger value, the individual is predicted to be female. It is expected that values within about 5% of the given values of A and B will be operational. More generally,

then, one can employ a function 43x – 120 as the male function, and 34x – 75 for the female function, with equivalent results. It will be apparent to one of skill in the art that statistically determined adjustments to the multipliers A and constants B could be made without departing from the spirit of the invention. This might be desirable, for example, in order to compensate for a significantly different racial mix in the general population, if the method were employed in an area where the racial mix differs from the mix in the sample population employed in the present example.

It will be apparent to one of skill in the art that in another embodiment of the invention, a data compilation may be assembled, wherein any given ridge width is associated with a probability that the individual is male or female. The data compilation may be as simple as a printed table or graph, or may be stored in computer-readable form for use by a computer.

Regarding sex, Table 6 illustrates that 94.4 percent of the randomly selected group of males and females were correctly classified. Only 14 individuals, of the total number of 250, were misclassified. 94.8 percent of the validation group was correctly classified, leaving only 13 individuals, of the 250, misclassified. This latter result is slightly better than the initial result and both are much greater than chance, which would have correctly classified approximately 50 percent of the cases.

Table 6.
Classification Results for Sex Using The Ten Finger Averages.

			Sex of Indiv.	Predicted Group Membership		Total
				Male	Female	
Random Group	Original	Count	Male	109	8	117
			Female	6	127	133
		%	Male	93.2	6.8	100.0
			Female	4.5	95.5	100.0
Validation Group	Original	Count	Male	128	5	133
			Female	8	109	117
		%	Male	96.2	3.8	100.0
			Female	6.8	93.2	100.0

The initial Fisher's function presented here was developed using the average of all of the ten fingers from each of the 500 individuals. Twelve more functions were created, one using the averages of the right hand only, the left hand only and then one function for each specific finger. Although it is usually not known which finger has left a print behind, because many are partials, sometimes it can be discerned. If there are opposing prints, there is a good chance that a thumb and an index finger are present. In these cases, the individual finger functions or the specific hand function, if more than three prints are present, can be employed.

The classification function coefficients for the hand averages and individual fingers are presented in Table 7, and the respected classification results are presented in Table 8. It should be noted, however, that the percent of the validation group correctly classified using the right hand average was 93.2 and the left hand was 94.0 percent. These results are very close to the predicted percent using the average from all ten fingers (94.8%). However, the functions employed for the individual fingers were not as successful as the functions using the averages. The percent of the validation group correctly classified using the R1 function was 85.6%, L1 was 87.2%, R2 was 83.2%, L2 was 80.4%, R3 was 89.2%, L3 was 88.0%, R4 was 82.3%, L4 was 88.0%, R5 was 86.7%, and L5 was 84.3%. The individual fingers may not have as accurate results as the overall or hand averages because, when using averages, the aberrant and unusual scores are balanced out from the larger sample size; with individual fingers, deviant numbers have more of an influence on the results.

Table 7.
Fisher's Classification Function Coefficients for Sex
Using Hand Averages and Individual Fingers.

	Male	Female
Right Hand Average (Constant)	36.118 -101.806	28.907 -65.464
Left Hand Average (Constant)	39.361 -110.054	30.746 -67.420
Right 1 (Constant)	16.424 -49.217	13.228 -32.167
Left 1 (Constant)	17.632 -52.614	13.448 -30.896
Right 2 (Constant)	17.725 -51.768	14.421 -34.501
Left 2 (Constant)	19.827 -56.966	15.565 -35.373
Right 3 (Constant)	17.943 -50.794	14.064 -31.475
Left 3 (Constant)	21.796 -61.345	16.936 -37.314
Right 4 (Constant)	21.111 -57.547	16.788 -36.645
Left 4 (Constant)	17.589 -47.719	13.812 -29.690
Right 5 (Constant)	23.115 -62.551	18.563 -40.587
Left 5 (Constant)	24.105 -64.643	19.254 -41.491

Although these results are still very successful, the percent correctly classified according to sex dropped using the individual finger functions by as much as 14.4 percent from the most successful ten finger average to the least successful finger which was L2. In order to see why this may be happening, the results from the individual partial correlation coefficients were matched against the corresponding discriminant analysis results. Initially, it was noted that as one variable, such as percent correctly classified, increased, the corresponding partial correlation coefficient went down, or closer to -1. A bivariate correlation was run to examine if there was a strong relationship between the success of classification from the discriminant scores and the corresponding partial correlation

coefficients. The result was -0.924, p.<0.001 illustrating a very strong and significant relationship between the two variables.

Since it is very difficult to determine which finger a latent finger print comes from, the data suggest using the formula created for the ten finger average measurement if the specific finger is unknown. Of course, if the finger or fingers can be determined, then that specific formula or the formula for that hand average would be more appropriate. However, when a partial or isolated print from an unknown finger is found, the formula chosen for determining the sex of that individual should be the ten finger average formula.

Since the previous tests run to determine the accuracy of these functions tested the specific function with the specific finger that function was created for, the accuracy of a print from an unknown finger is still not known. Therefore, a subset of 60 individuals, thirty males and thirty females, was chosen randomly from the original 500 individuals to test that specific scenario. Since the exact finger of an isolated print is usually not known, all ten finger measurements taken from each of the 60 individuals were used in both the male and the female formulae created for the ten finger average. The formula for the ten finger average was chosen to be used in this test procedure because it is the most accurate of all of the formulas. In addition, this formula was created using the average measurements of all of the fingers of both hands, generating a result that averages out deviant or aberrant measurements. This final test was run so that a print, from any finger, found at a crime scene, will have a predicted accuracy based on the ten finger average formula.

Each of the ten finger measurements of every individual was used for both the male and female formulas for the ten finger average; those correctly classified were calculated together for predictive purposes. The results, presented in Table 9 are as follows. The percentage correctly classified using the ten finger average formula for the males R1 was 87%, R2 was 97%, R3 was 87%, R4 was 73%, L1 was 100%, L2 was 97%, L3was 80%, l4 was 77%

and L5 was 57%. The percentage correctly classified using the formula for the ten finger average for the females was R1 83%, R2 was 77%, R3 was 87%, R4 was 93%, R5 was 93%, L1 was 87%, L2 was 76%, L3 was 100%, L4 was 90% and L5 was 90%. The overall lowest score predicted for the male sample was at 57% on L5, while the lowest predicted score for the females was 76% on L2. Both the males and females had a finger with a predicted score of 100%, L1 and L3 respectively. Regarding the females, their overall accuracy for predicting sex, using the ten finger average formula applied to each specific finger and then combining the results, was 87.3%. Using the male sample, the overall score for all of the fingers combined, predicting sex using the formula for the ten finger average with each individual finger measurement was 82.0%. What this illustrates is, if a random finger print from an unknown finger is found, using the formula created for the ten finger average, one could predict the sex of the individual accurately between 76% and 100% of the time for an average correct classification of 87.3% for females. For males, the correct classification of sex from an unknown digital print could be between 57% and 100% of the time with an average correct classification of 82%. This result is significantly better than chance which could only predict accurately the sex of an individual 50% of the time.

Table 9.
Percent Correctly Classified According to Sex of the 60 Test Individuals Using the Ten Finger Average Formula.

	R1	R2	R3	R4	R5	L1	L2	L3	L4	L5
Males	87%	97%	87%	67%	73%	100%	97%	80%	77%	57%
Females	83%	77%	87%	93%	93%	87%	76%	100%	90%	90%

Therefore, the hypothesis that the sex of an individual can be predicted based on a finger tip ridge breadth measurement was supported in this analysis. For the sexes combined, the average of all ten fingers allows for the most accurate prediction of sex at 94.8%, with R3 being the finger with the most accurate predictive ability and L2 the least accurate finger used

to predict sex at 80.4% correctly classified. These predictions, however, were executed with those specific finger's own formula. Assuming the finger is not initially known, using the ten finger average formula for any digit yields slightly different results. For the males, L5 was the least accurate finger with a result of 57% while L1 was 100% accurate. With regard to the females, L2 was the least accurate digit at 76% while L3 yielded 100% accuracy. Overall however, the accuracy in predicting an individual's sex if the digit is unknown is 87.3% for females and 82.2% for males. These final results are most likely what will be used in a real investigation, since the actual finger from which a latent print comes from is usually not known.

Summary

The statistics employed here illustrate the utility of finger tip ridge breadth measurements in determining probable gender. When comparing the males to the females, there was a 1.14 cm difference between their overall mean measurements of the average of all ten fingers. The T-Test determined that this difference was significant. Pearson's bivariate correlation indicated that there was a strong relationship between sex, and ridge breadth. The Partial F-Test tested the strength of this relationship, and sex had strong predictive value. Finally, a discriminant analysis was performed to determine if an individual's sex or weight category could be predicted using a finger tip ridge breadth measurement. These results demonstrate that ridge breadth has very strong predictive abilities with regard to an individual's sex, and that finger tip ridge breadth measurement can be used to very accurately predict an individual's sex. The invention provides a predictive model that can be used to determine the sex of an individual based on a finger tip ridge breadth measurement.

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CLAIMS

I CLAIM

1. A method of determining the probable sex of an unknown individual, said method comprising the step of measuring the ridge width in one or more of said individual's fingerprints.

2. The method of claim 1, wherein the ridge width is measured by measuring the overall width of a plurality of parallel ridges.

3. The method of claim 2, wherein the ridge width is measured by measuring the overall width of from two to ten parallel ridges.

4. The method of claim 1, further comprising the step of comparing the measured ridge width to a data compilation which correlates ridge width with probable gender.

5. The method of claim 4, wherein the step of comparing the measured ridge width to the data compilation is carried out by means of a computer, which outputs the probable gender.

6. The method of claim 5, wherein the measurement of ridge width is carried out by a process of computerized image analysis.

7. The method of claim 1, wherein the method further comprises the steps of

(a) calculating the result P_m of the male formula $P_m = A_m x - B_m$, wherein

(i) x is the sum distance in centimeters, either measured or extrapolated, across 100 fingerprint ridges,

(ii) A_m is about 41-45, and

(iii) B_m is about 114-126; and

(b) calculating the result P_f of the female formula $P_f = A_f x - B_f$, wherein

(i) x is the sum distance in centimeters, either measured or extrapolated, across 100 fingerprint ridges,

(ii) A_f is about 32-36, and

(iii) B_f is about 71-79; and

if $P_m > P_f$, determining that the individual is probably male, and if $P_f > P_m$, determining that the individual is probably female.

8. The method of claim 1, wherein the method further comprises the steps of

(a) calculating the result P_m of the male formula $P_m = A_m x - B_m$, wherein

(i) x is the sum distance in centimeters, either measured or extrapolated,

across 100 fingerprint ridges,

(ii) A_m is 43, and

(iii) B_m is 120; and

(b) calculating the result P_f of the female formula $P_f = A_f x - B_f$, wherein

(i) x is the sum distance in centimeters, either measured or extrapolated, across 100 fingerprint ridges,

(ii) A_f is 34, and

(iii) B_f is 75; and

if $P_m > P_f$, determining that the individual is probably male, and if $P_f > P_m$, determining that the individual is probably female.

9. A device comprising an image analyzer component which displays an image of the fingerprint of an individual, further comprising a means for inputting to the analyzer the coordinates of a line segment normal to a plurality of parallel fingerprint ridges, wherein said device computes the length of the line segment and computes the probable gender of the individual by the method of claim 4.

10. A device comprising an image analyzer component which displays an image of the fingerprint of an individual, further comprising a means for inputting to the analyzer the coordinates of a line segment normal to a plurality of parallel fingerprint ridges, wherein said device computes the length of the line segment and computes the probable gender of the individual by the method of claim 7.

11. A data compilation which correlates fingerprint ridge width with probable gender.

12. The compilation of claim 11 wherein the compilation is visually readable.

13. The compilation of claim 11 wherein the compilation is in computer-readable format.

14. A computer-readable medium, carrying the data compilation of claim 13.

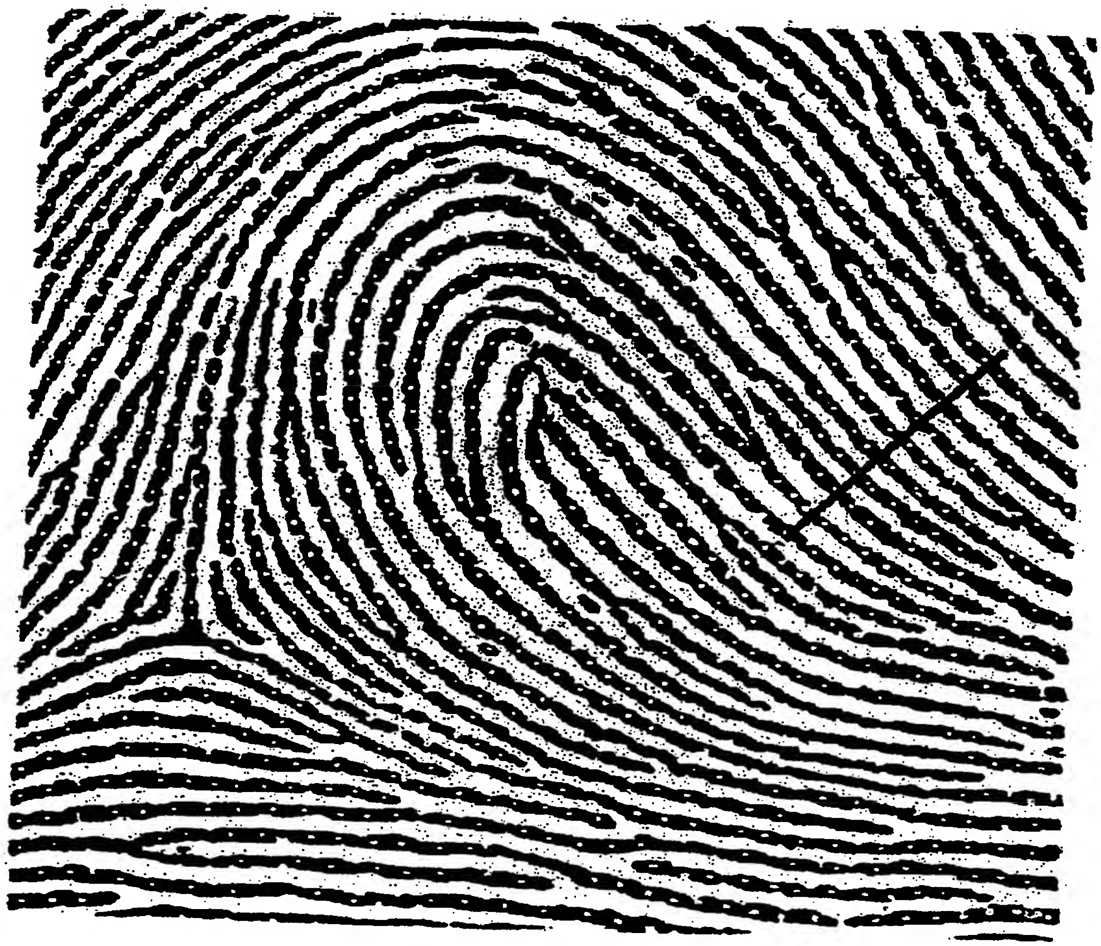

Figure 1

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 00/03338

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G06K9/00 A61B5/117

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G06K A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	ZAVALA A ET AL: "Using fingerprint measures to predict other anthropometric variables" HUMAN FACTORS, DEC. 1975, USA, vol. 17, no. 6, pages 591-602, XP000914083 ISSN: 0018-7208 page 600, right-hand column, paragraph 3 - paragraph 4	1-6,9, 11-14

☐ Further documents are listed in the continuation of box C.

☐ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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Date of the actual completion of the international search	Date of mailing of the international search report
7 June 2000	19/06/2000

Name and mailing address of the ISA	Authorized officer
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